OPTIMIZATION OF ACCELERATORS AND LIGHT SOURCES WITHIN OPAC

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on behalf of the oPAC Consortium

Abstract

The optimization of particle accelerators and light sources by combining studies into beam physics, instrumentation, numerical simulations and accelerator control systems is the aim of the EU-funded oPAC project. With a budget of more than 6 M€, oPAC is one of the largest training networks ever funded by the EU and currently trains more than 20 Marie Curie Fellows. This paper presents selected research highlights, including optimization studies into the CERN Proton Synchrotron (PS), measurement and correction of linear and nonlinear optics distortions in the ALBA synchrotron (Spain), perturbation measurements of a cavity Schottky noise detector at GSI (Germany) and R&D into device control data base tool at COSYLAB (Slovenia). Moreover, a summary of past and future oPAC events is also given.

INTRODUCTION

The Optimization of Particle ACcelerators (oPAC) project started on 1.12.2011 and over its project duration of 48 months, 22 early stage researchers are developing beyond state-of-the-art technologies and techniques that will help optimizing existing and future accelerators and light sources [1]. Following an international recruitment campaign, all Fellows are now in employment at universities, national and international research centers, as well as private companies across Europe. More than 20 associated and adjunct partners complement the consortium and contribute to the R&D program by offering scientific collaboration, secondment opportunities to all Fellows with a focus on cross-sector experience, and actively contributing to the network's many scientific and training events.

RESEARCH

oPAC is structured into four R&D work packages: beam physics, beam diagnostics, simulation tools and accelerator control and data acquisition systems. Fellow R&S stretches across these work packages and targets the optimization of existing and future accelerator-based infrastructures. The following paragraphs present the R&D results in a few selected projects.

Optimization Studies into the CERN PS

As part of the LHC Injector Upgrade project, the CERN PS Booster will be required to operate at nearly doubled intensity with little allowable increase in emittance growth or beam loss. The larger tune footprint will make it no longer possible to avoid all dangerous resonances. A campaign of nonlinear optics measurements from turn-by-turn trajectory measurements, with the goal of characterizing and then compensating for higher-order resonances, is planned for after Long Shutdown 1. A commonly-used method for studying nonlinear optics in a synchrotron involves using an AC dipole to drive large coherent betatron oscillations, and then analyzing the frequency components of the trajectory. In the PS Booster, the significant direct space charge effects may complicate this procedure. Simulations are hence needed to understand the effects of space charge on the response of the beam to the AC dipole and on the observed driven beam trajectories. The results of tracking simulations with space charge effects and an AC dipole, and comparisons of simulated results with trial measurements have been carried out by M. McAteer at CERN and are presented in more detail in [2]. In addition, a transverse instability has long been observed in the PS Booster near the beginning of the acceleration ramp. The instability is adequately suppressed by the transverse damper during normal operation, but without the damper over half of the beam intensity is lost. The cause of this instability had not been well-understood, but recent measurements of the turn-by-turn beam trajectory have offered some insight.

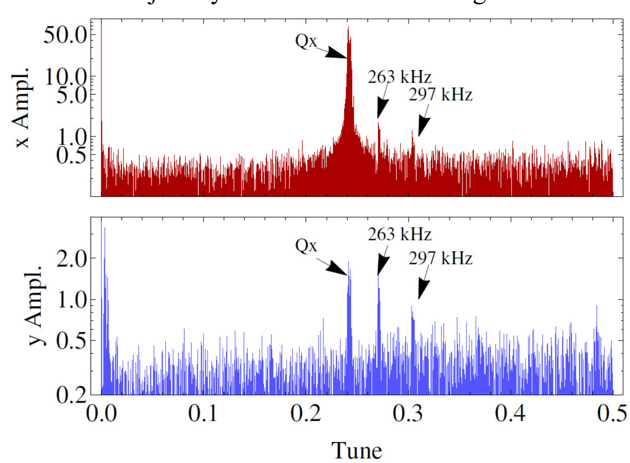

Figure 1: Spectrum of horizontal and vertical beam trajectories during turns 85,000-90,000 [3].

The spectrum of turn-by-turn trajectory shows two prominent peaks in each plane, in addition to the tunes. These peaks always occur at a fixed frequency throughout the entire acceleration cycle. There is a very specific relationship between the frequency of these noise peaks and the horizontal tune when the transverse instability occurs, so it seems clear that they correspond to a real perturbing force on the beam, rather than spurious noise in the BPM electronics. It is expected that the cause of this perturbation can be located more precisely in the

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future when data from BPMs is available so it can ultimately be corrected [3].

Storage Ring Performance Improvement Using Optimization Based on Genetic Algorithms

An important challenge for current and future third generation synchrotron light sources is to optimize the linear and the non-linear beam dynamics of strong focusing lattices. This is a multi-objective problem that involves a high number of constraints and a multi-dimensional parameter space. oPAC Fellow X. Gavalda who is based at the SOLEIL light source in France has used a Multi-Objective Genetic Algorithm (MOGA) [4] and the tracking code ELEGANT [5] to optimize the linear and non-linear beam dynamics of SOLEIL. Genetic Algorithms [6] are a heuristic search that mimics the process of natural selection and generates solutions to optimization problems using techniques inspired by natural evolution, such as mutation, selection and evolution. These kinds of computational tools require a cluster with hundreds of processors working in some cases during one month.

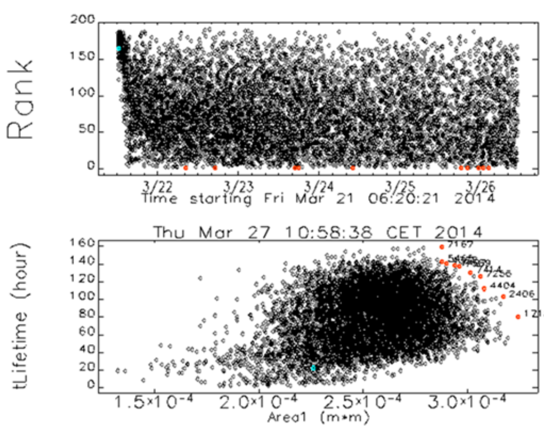

Figure 2: Optimization results of MOGA using 2 quadrupoles, 11 families of sextupoles without magnetic errors or vacuum chambers at SOLEIL during 5 days [7].

First, the effects of the sextupoles on the beam dynamics of the machine were optimized. Whilst sextupoles are required to correct the natural chromaticity introduced by quadrupoles, they also introduce non-linearities that can reduce the dynamical aperture and the momentum aperture significantly. In a second step, MOGA-based optimization will be the basis to propose a list of possible upgrades of the accelerator, see Fig. 2 for an example [7]. These upgrades will target a reduction of the effective horizontal emittance while keeping the ring circumference and the number of beam lines constant. As a consequence, this shall increase the brightness of the facility.

Perturbation Measurements of a Model Cavity at GSI

Lately several batches of perturbation measurements of a model cavity using ceramic rod and bead have been carried out by oPAC Fellow X. Chen at GSI, Darmstadt in Germany. The cavity was manufactured and delivered to GSI at the end of last year. It has been used as a prototype to prove the design concept of a cavity-based, transversely sensitive, heavy-ion detector by means of Schottky noises. Tests were carried out on a dedicated platform for shunt impedance measurements of the cavity. In the setup the circular cavity stands on a 2-D high-precision movement unit, consisting of two active tracks and two passive tracks. A 3 mm thick ceramic rod goes through the beam pipe and is fastened to a pair of height gauges at both sides of the cavity. Those gauges are aligned to the direction of the pipe and precisely fine-tuned to the same height by hand. Two feed throughs are mounted on the circumference of the cavity and connected to a network analyzer via phase-stable supraflex cables.

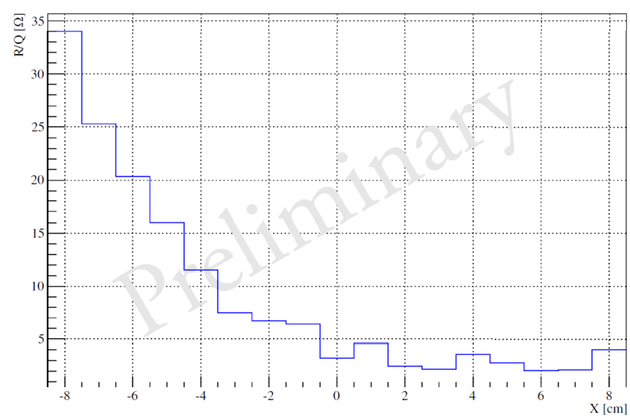

Figure 3: Distribution of the shunt impedance [8].

The whole measurement setup lies on a vibration damped optical table to ensure least mechanical disturbance from the environment. The motor controller and the network analyzer are connected to a host PC via Ethernet cables and can thus be controlled by a deliberately developed Java code to realize automatic procedures for the measurements. Following the PC's commands, the cavity goes to each sampling position while the analyzer measures the transmission coefficient between the two ports and transfers the data back to the PC in real time. Afterwards the data can be analyzed offline using a purpose-written C++ code based on the ROOT library. Through evaluating the changes of the resonant frequencies of the cavity caused by perturbation of the inserted rod or bead at different places, one can deduce the shunt impedance of the cavity with respect to different beam positions inside the pipe. Fig. 3 shows preliminary results of the reduced shunt impedance obtained via such measurements. See [8] for further details.

Device Control Database Tool (DCDB)

In a research facility containing numerous instruments, it is advantageous to reduce the amount of effort and repetitive work needed for changing the control system

(CS) configuration: adding new devices, moving instruments from beam line to beam line, etc. P. Maslovat COSYLAB has developed a CS configuration tool which provides an easy-to-use interface for quick configuration of the entire facility. It uses Microsoft Excel as front-end application and allows the user to quickly generate and deploy IOC configuration, such as EPICS start-up scripts, alarms and archive configuration, onto IOCs. The DCDB tool utilizes a relational database which stores information about all elements of the accelerator. The communication between the client, database and IOCs is realized by a REST server written in Python. The key feature of the DCDB tool is that the user does not need to recompile the source code. It is achieved by using a dynamic library loader, which automatically loads and links device support libraries, see Fig. 4.

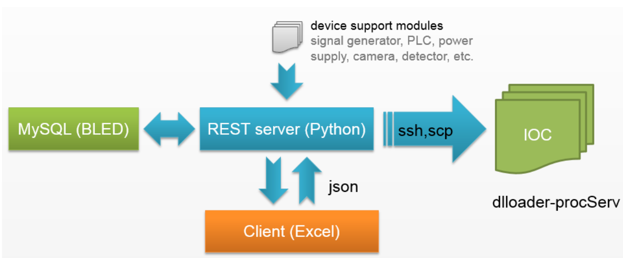

Figure 4: Overview of DCDB architecture.

The DCDB-tool uses a MySQL relational database together with the ESS-BLED schema. The backend is a typical web-server, realized with a combination of the following python modules: flask-restful (REST server), sqlalchemy and pymysql (database communication layer) and paramiko (ssh). The front-end is a Microsoft Excel plugin written in C# using .NET technology. Finally, the IOCs are Linux machines running EPICS and the client-server communication is based on the exchange of JSON objects (strings). The DCDB tool is compliant with CODAC which is used e.g. at ITER or ESS, but can also be used in any other EPICS environment.

TRAINING EVENTS

The fundamental core of the training is a dedicated cutting-edge research project for each Fellow at their host institution. The network is then used to provide opportunities for secondments for all Fellows to spend time working at other institutions within the network for hands-on training in specific relevant techniques and for broader experience including different sectors. Most Fellows will be in post for 36 months and are registered into a PhD program. This local training will be complemented by a series of network-wide events that include external participation.

International Schools

As an introduction to the field of accelerator science all recruited oPAC Fellows took part in either the CERN Accelerator School in autumn 2012 or the Joint Universities Accelerator School (JUAS) in 2013 or 2014. Several oPAC Schools will be held throughout the four years of the project and bring together experts from across the world, in focused research areas, to discuss the present state-of-the-art and review challenges with the networks' researchers. An international School on Accelerator Optimization will be held at Royal Holloway University of London in July 2014 and cover beam physics, instrumentation R&D and charged particle beam simulations at an advanced level [9]. It targets PhD students, Postdocs, as well as experienced researchers.

Topical Workshops

A series of Topical Workshops will cover all important research areas within the network. The first of these on Challenges in Accelerator Optimization took place at CERN, Geneva in June 2013 and attracted more than 100 delegates [10]. In 2014 workshops took place at CIVIDEC on Beam Diagnostics [11] and on Libera Technology at Instrumentation Technologies [1]. In 2015 the University of Liverpool will host a workshop on Technology Transfer for all oPAC Fellows. Participation to these workshops is also open to scientists external to the network and there are opportunities for scholarships to support early career researchers from outside the network. In addition, specialist hands-on workshops have been provided by Bergoz on Beam Instrumentation and by CST offering training in Particle Studio.

Conference on Accelerator Optimization

A three day International Conference will be hosted by the national accelerator center (CNA) in Seville, Spain in the final year of the oPAC project. It will promote all research outcomes and enable the Fellows to engage with other university groups and private companies. The conference will also present an opportunity for follow-up activities between the oPAC partners and participating scientists from outside the network and thus serve as a career platform for all Fellows.

A Symposium on 26 June 2015 on Accelerators and Lasers for Science and Society will be organized at the Liverpool Convention Center as a finale to the outreach activities undertaken during the course of the network. This will present the main project findings in an understandable way for the general public emphasizing the possible applications of the technologies concerned.

SUMMARY AND OUTLOOK

In this paper selected research results from the oPAC project were presented along with an overview of past and future events. The project was commended as a 'success story' by the in 2013 which underlines impressively the excellence of the work carried out to date.

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